The Muon Ionization Cooling Experiment MICE

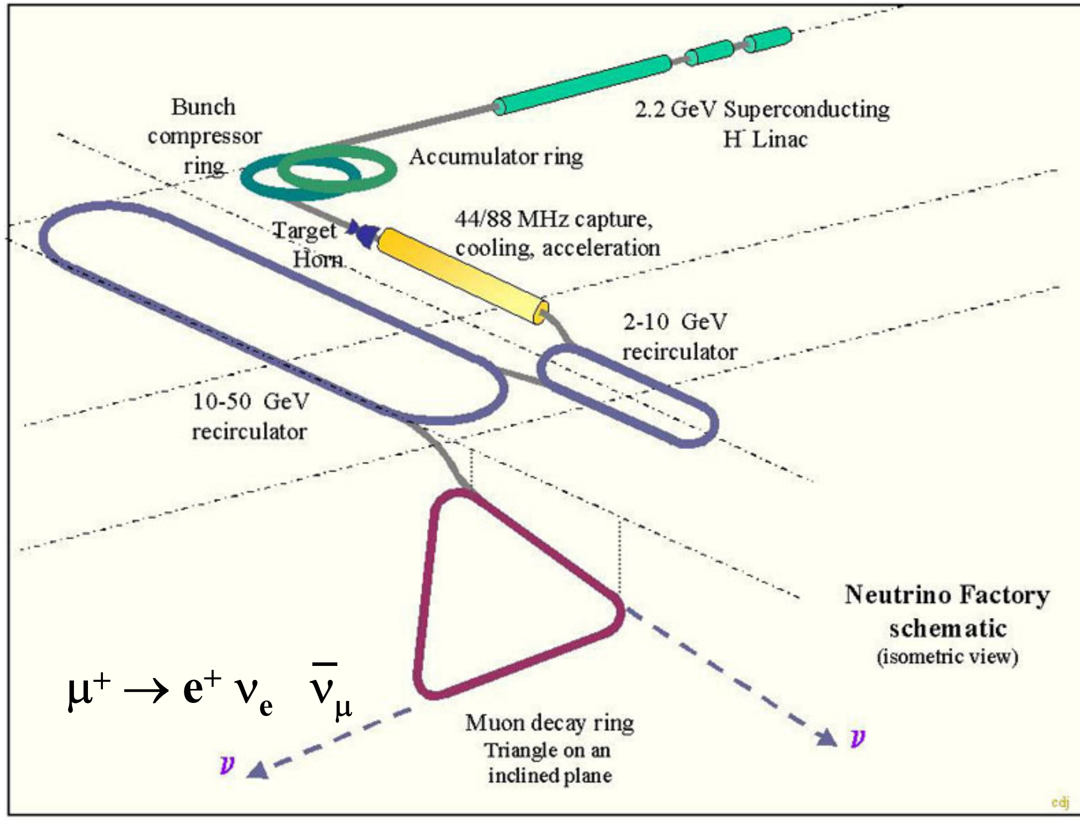
International workshops:
NUFACT 99 (Lyon, France)
NUFACT 00 (Montery, California)
NUFACT 01 (Tsukuba, Japan)
NUFACT 02 (London, UK)

$\Rightarrow$ Neutrino Factory
is the ultimate tool for study
of Neutrino Oscillations

-- unique source of high energy ν_e

--reach/sensitivity better by
order(s) of magnitude wrt other
techniques (e.g. super-beams) for

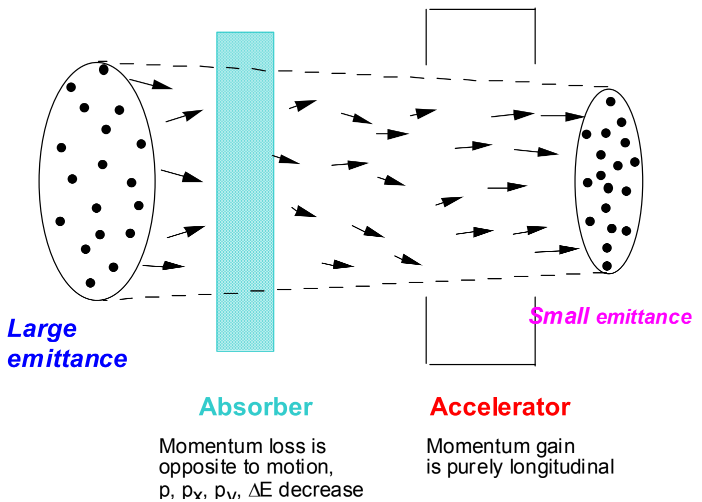
* θ_{13} *
** matter effects **
*** leptonic CP violation ***



Cooling needed to reduce emittance of muon
Beam so that it fits into accelerator

Muon Ionization Cooling

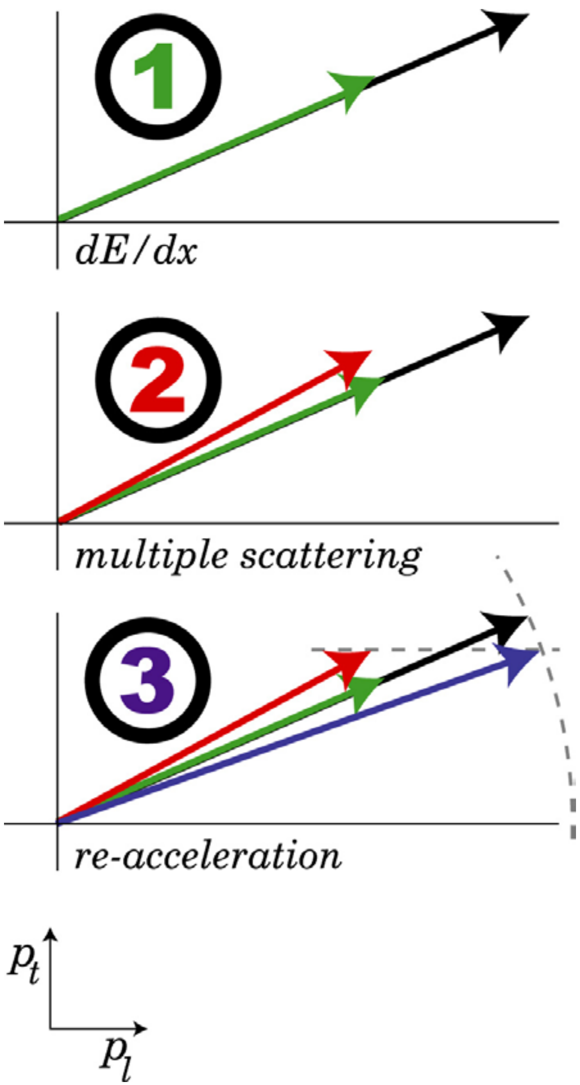
- Although the concept of muon ionization cooling is relatively straightforward (transverse, at least)
  - Muons pass through material losing energy
  - They are then accelerated regaining only longitudinal momentum



$$\frac{d\epsilon_N}{ds} = -\frac{1}{\beta^2}\frac{dE_\mu}{ds}\frac{\epsilon_N}{E_\mu} + \frac{\beta_\perp (0.014 \text{ GeV})^2}{2\beta^3 E_\mu m_\mu L_R}$$

- However, theory is sometimes much simpler than reality

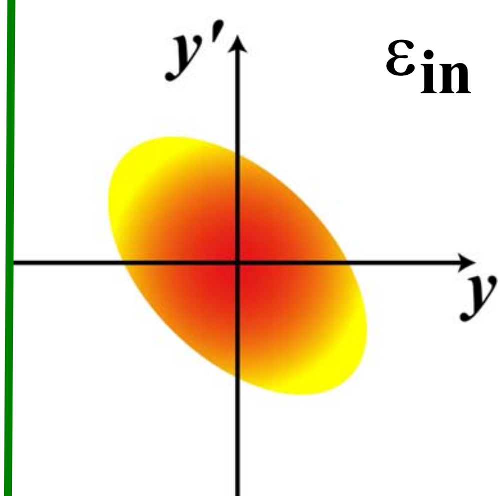
Ionization cooling-One dimensional example

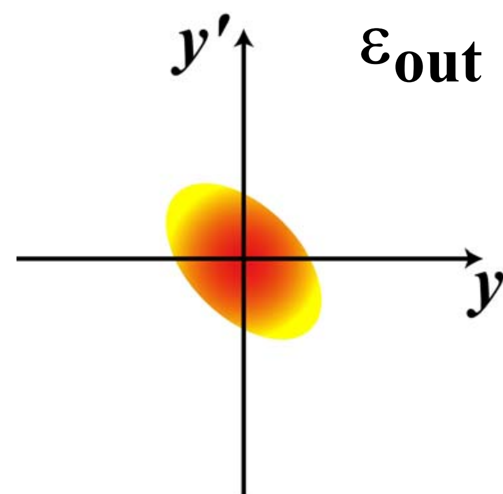


$$m = \begin{pmatrix} y \\ y' \end{pmatrix} \qquad y' = \frac{\partial y}{\partial z} = \frac{p_y}{p_z}$$

$$V = \langle m m^{\mathrm{T}} \rangle = \begin{pmatrix} \sigma_y^2 & \sigma_{yy'} \\ \sigma_{yy'} & \sigma_{y'}^2 \end{pmatrix}$$

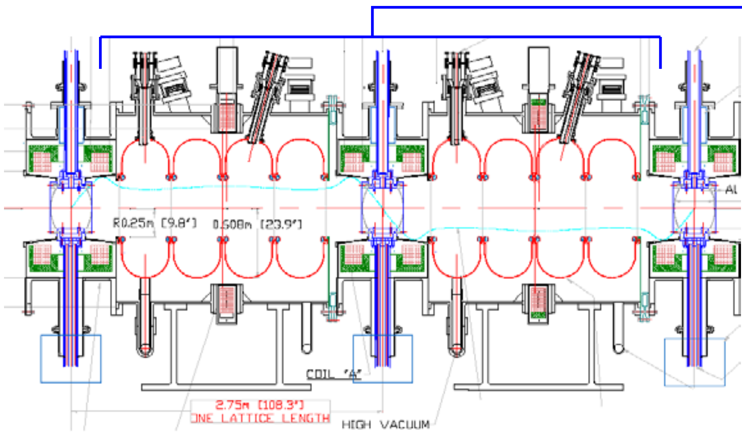
$$\varepsilon = \sqrt{\det(V)}$$



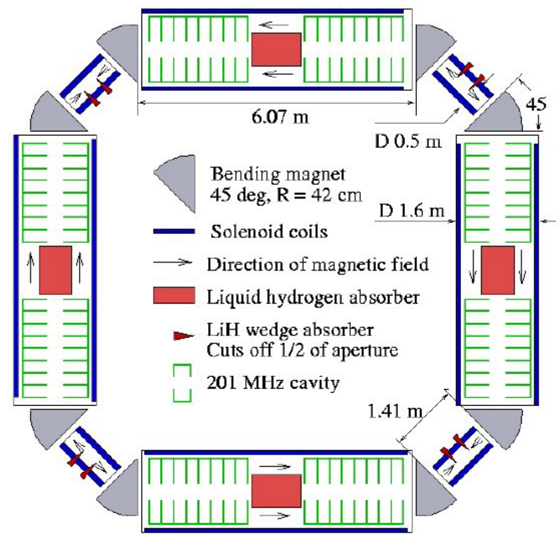


Muon Ionization Cooling

- There are both linear and ring implementations proposed for muon ionization cooling …



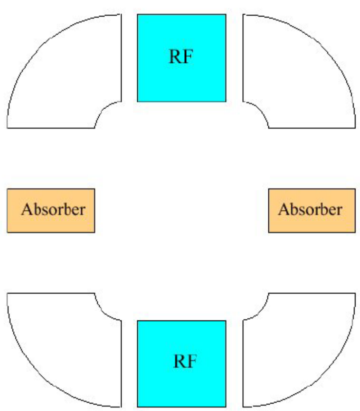
SFOFO



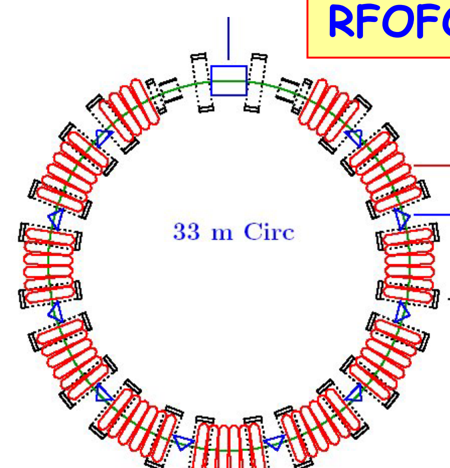
Solenoid Focused Ring

RFOFO

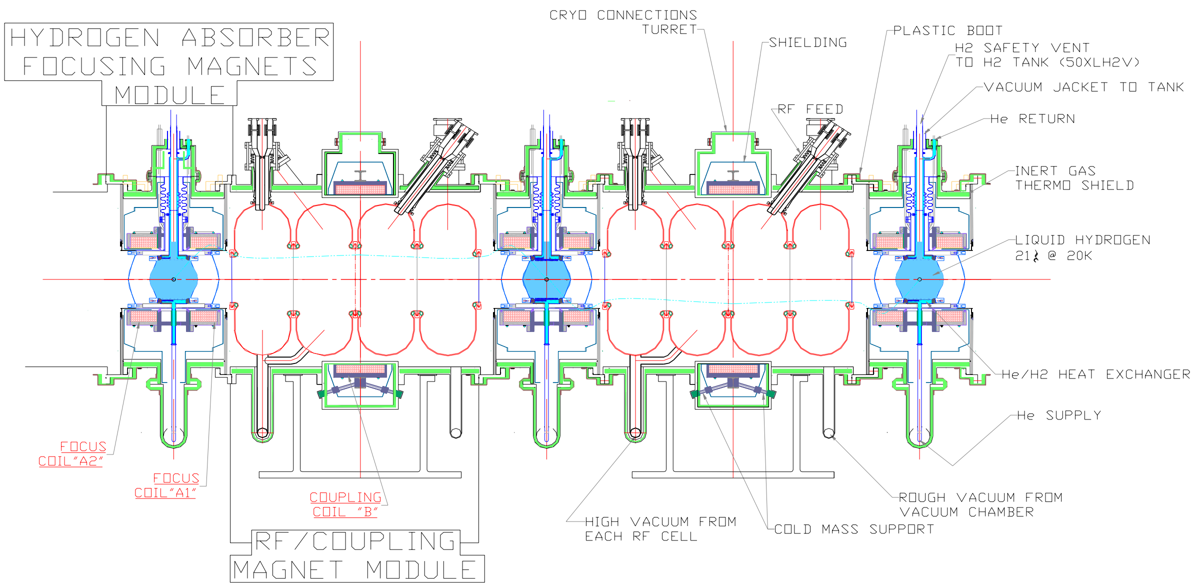
Graded Dipole



Note: Rings provide 6D cooling and therefore present some differences in implementation



Ionization Cooling Apparatus



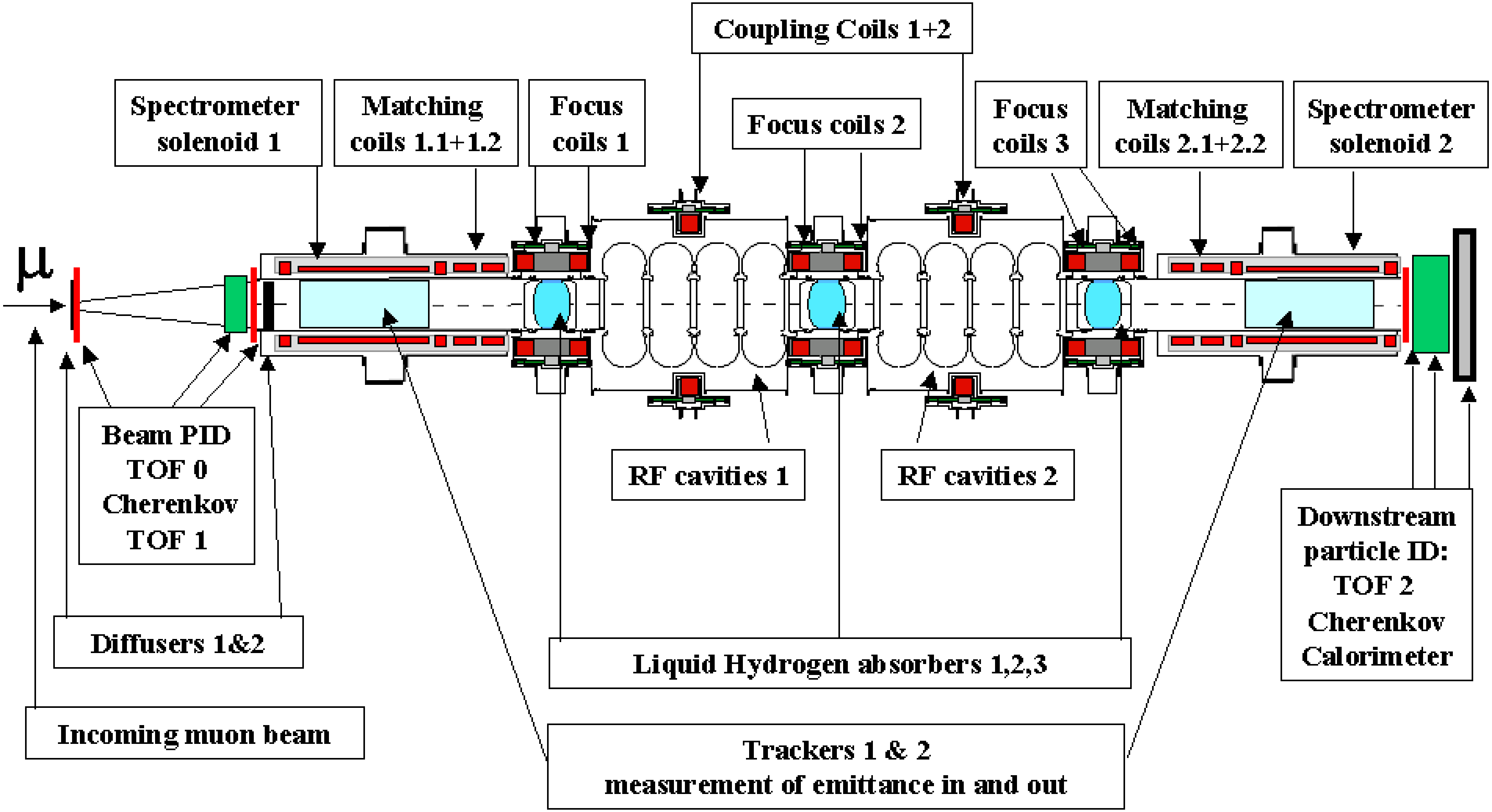
A delicate technology and integration problem
⇒ Need to build a realistic prototype and verify that it works (i.e. cools a beam)

Difficulty: affordable prototype of cooling section only cools beam by 10%, while standard emittance measurements barely achieve this precision.

Solution: measure the beam particle-by-particle

state-of-the-art particle physics instrumentation will test state-of-the-art accelerator technology.

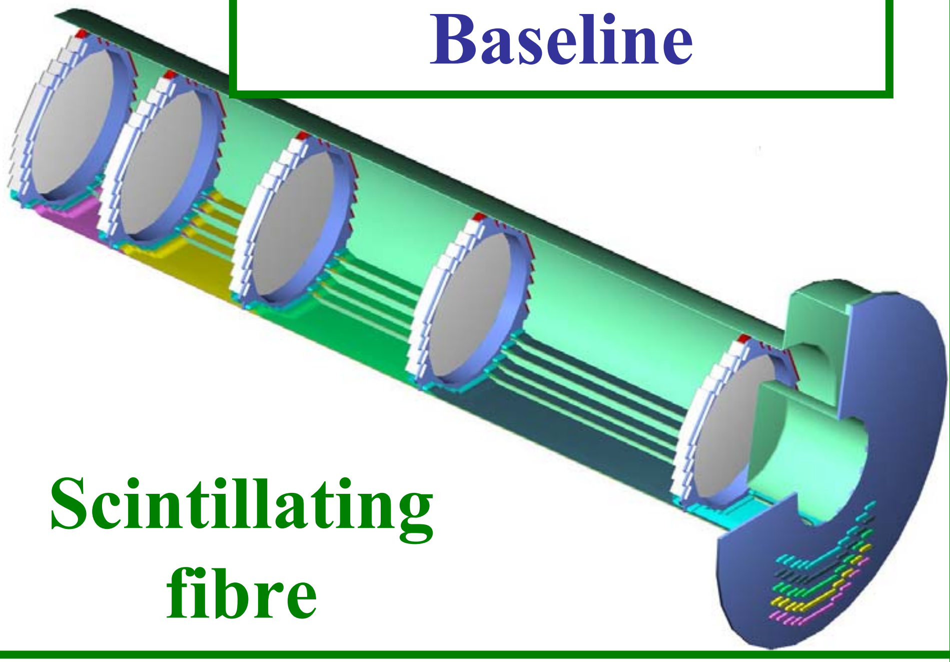
The MICE apparatus



NB: Particle identification crucial – to avoid bias in $\Delta\varepsilon$ require non-muon contamination in final sample must be *at most* 1‰

Tracker

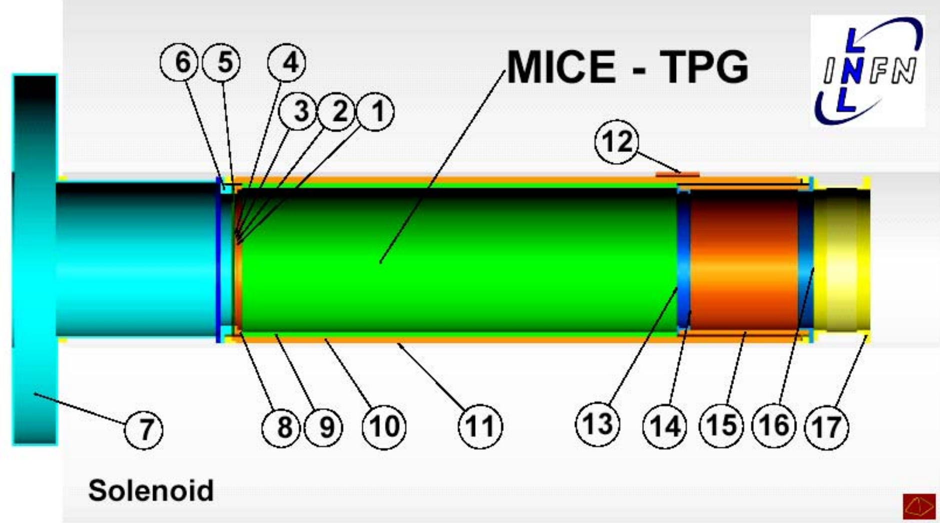
Baseline



Scintillating fibre

- No active electronics/HV close to liquid hydrogen absorber
- 350 μ fiber: 3-fold doublet; 0.35% X_0
- VLPC read-out: high quantum-efficiency, high gain
- Modular construction
- If each scintillating fiber is readout ⇒ high channel count

Alternative



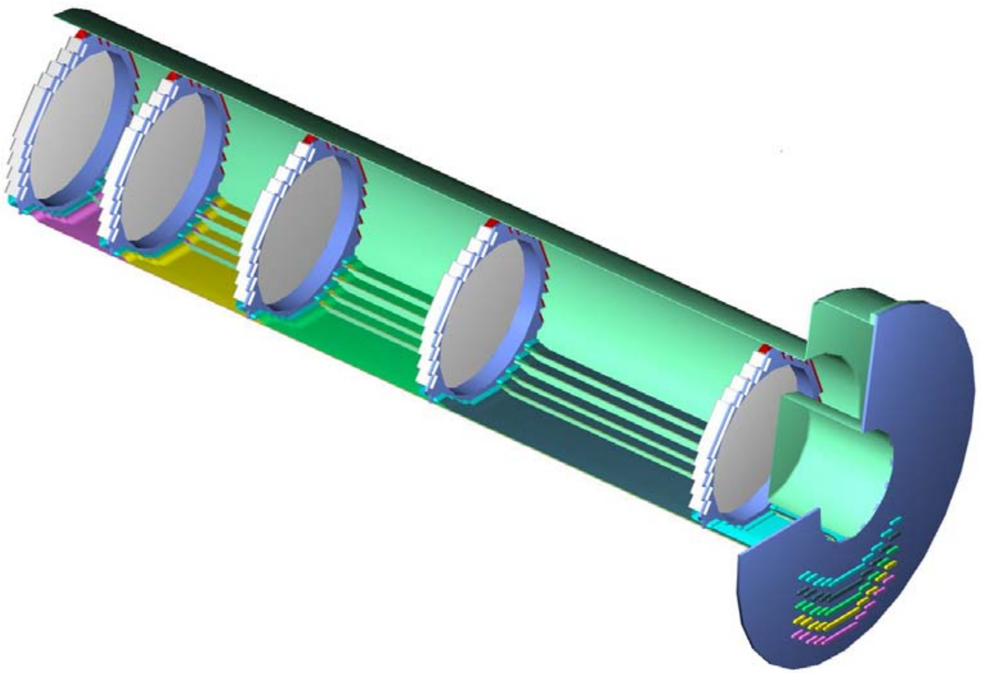
TPG – TPC with GEM readout

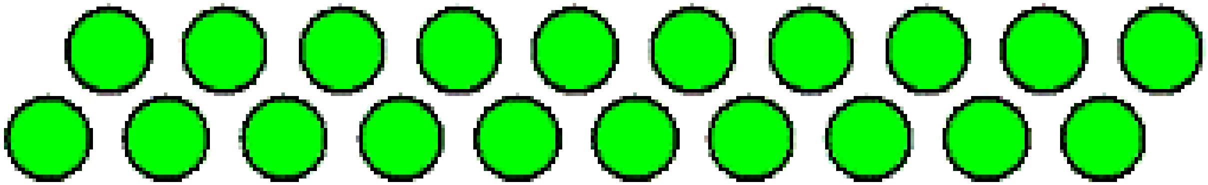
- Light gas (0.15% X_0)
- Many points per track
- High precision track rec^{n} possible
- Potential cost saving
- Large integration time
- Effect of X-rays on GEMs

Scintillating-fibre tracker

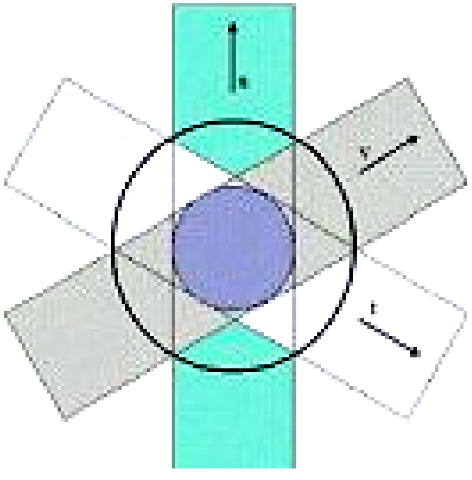
MICE SciFi group:

UK groups
with IIT, KEK,
Osaka, (Fermilab)
Meta-Group





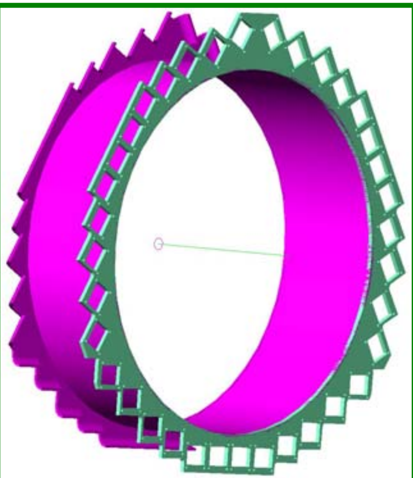
a)

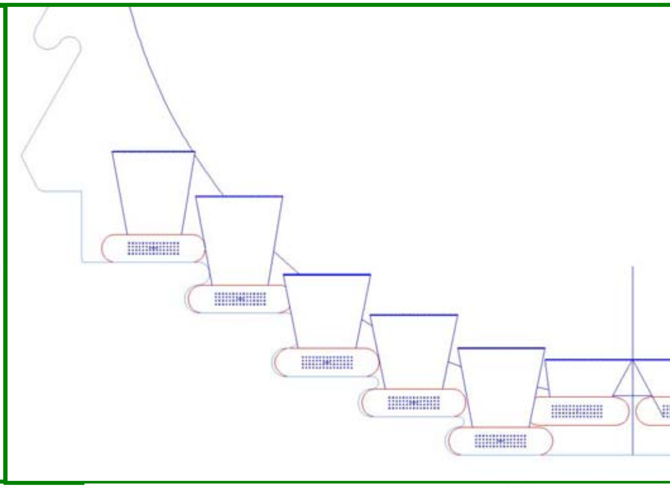


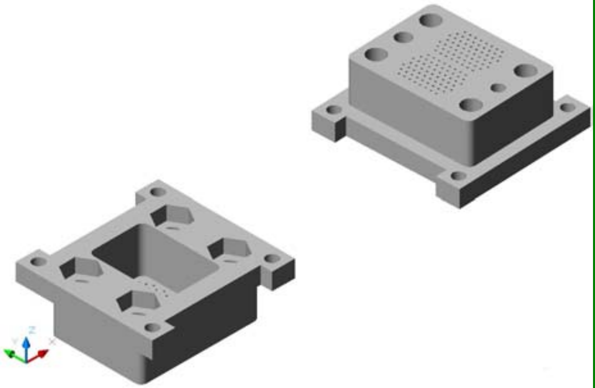
b)

Status: mechanical design

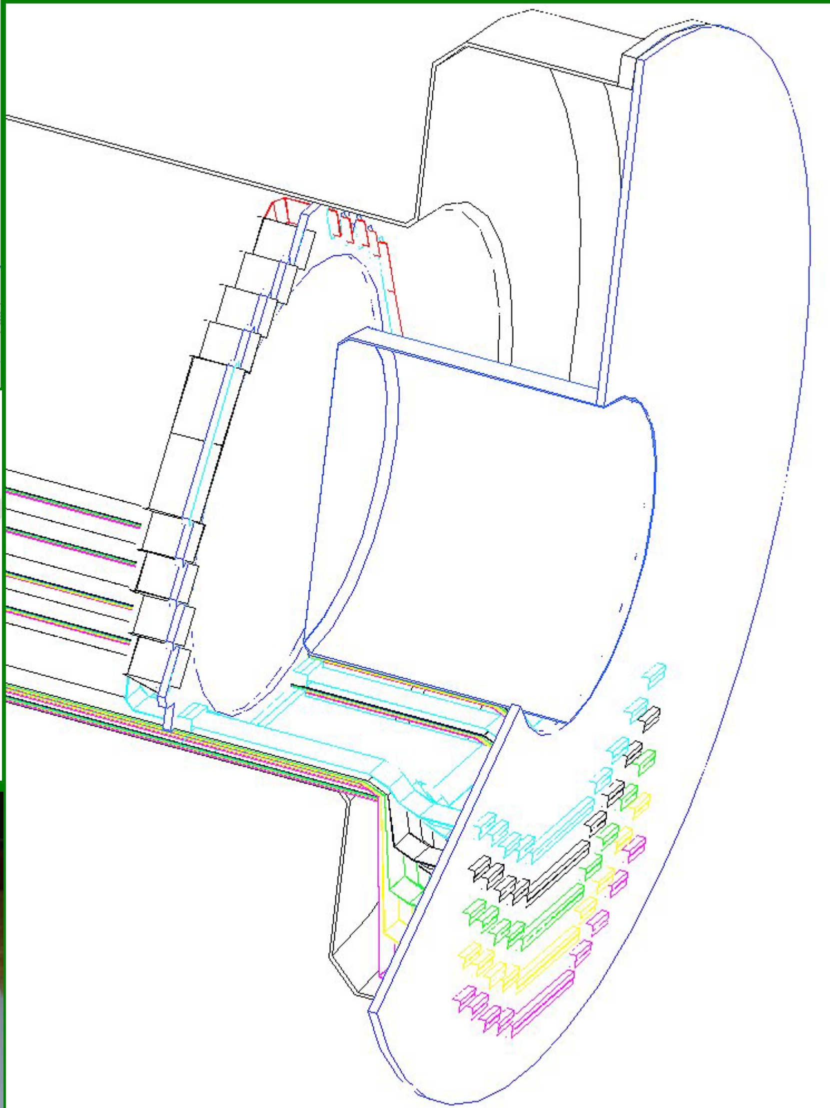
Fibre station:





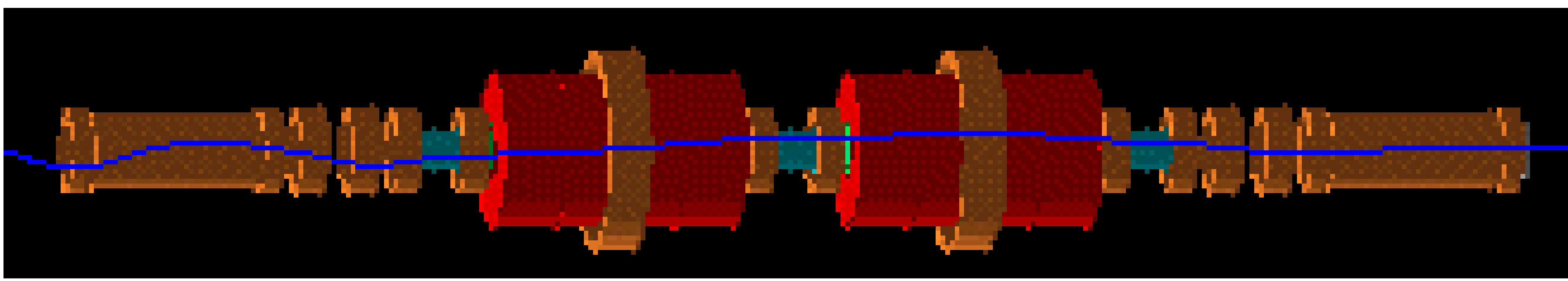


#1 'services ring'

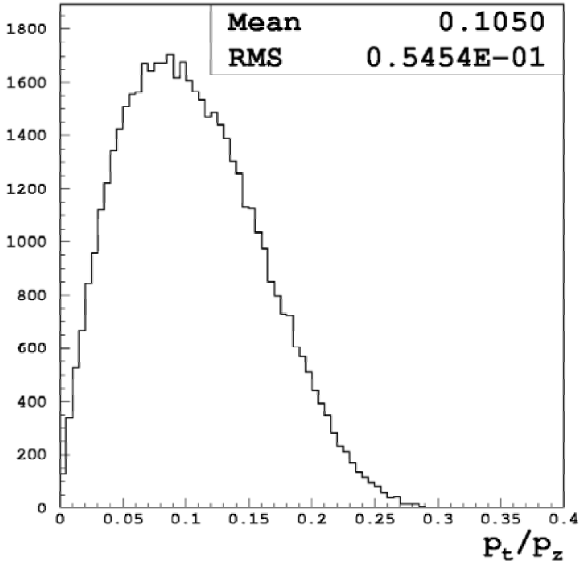


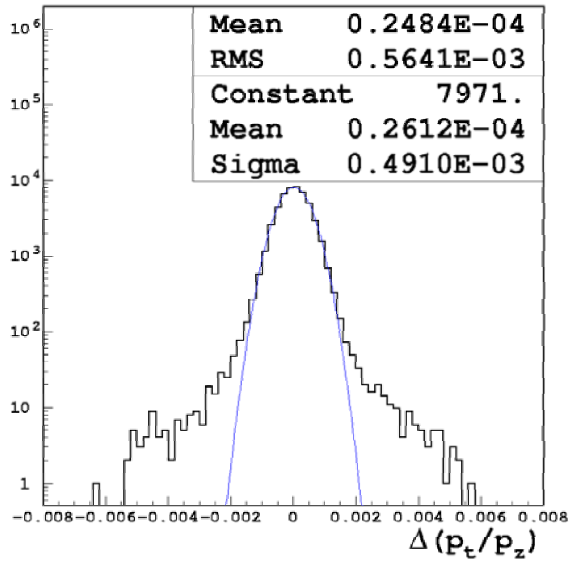
Tracker simulation

- **Status:**
  - Simulation: first full simulation of MICE implemented in Geant4
  - Reconstruction: first implementation of pattern-recognition and track-fitting algorithms
  - Long-term foundation for MICE software

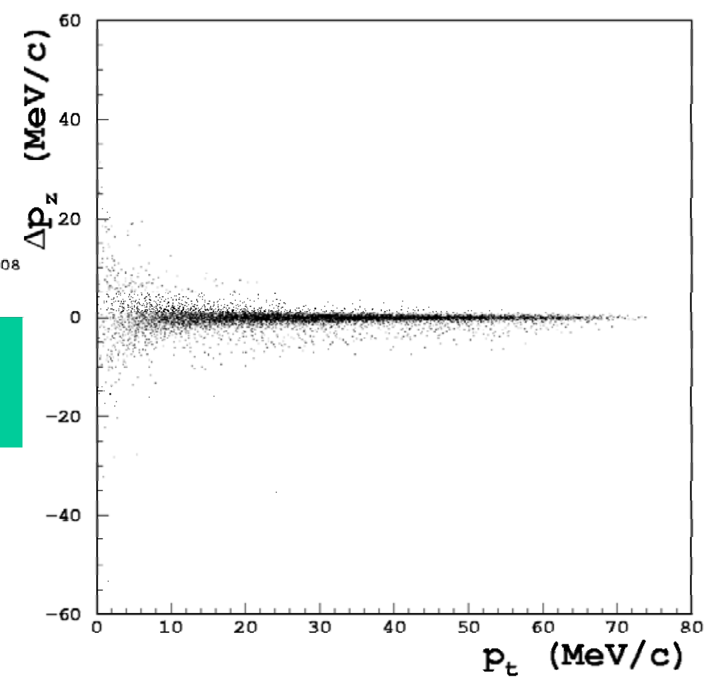


Scintillating-fiber tracker



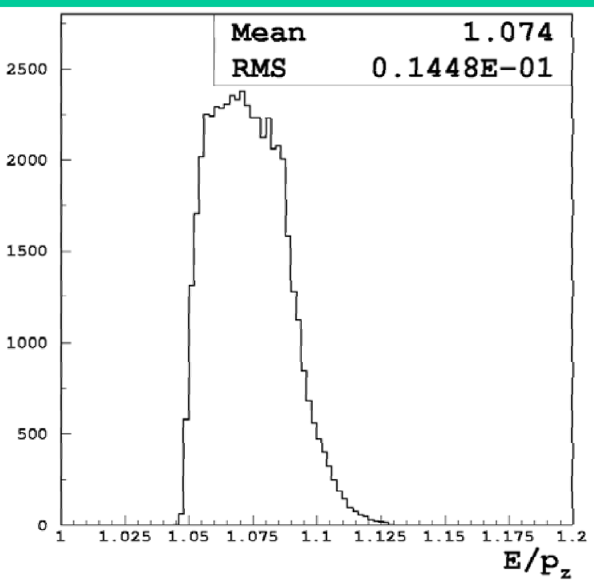


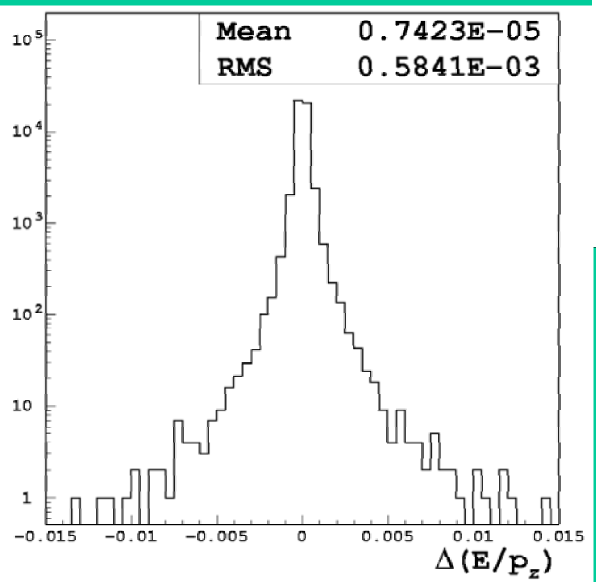
$\sigma(p_T) = 110$ keV



$\sigma(p_T/p_z) \sim 0.06\%$

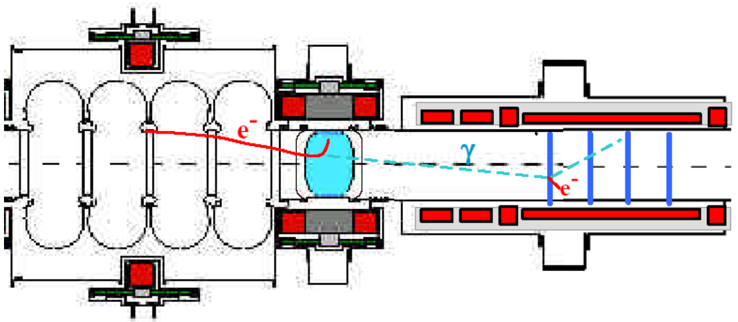
$\sigma(E/p_z) \sim 0.06\%$



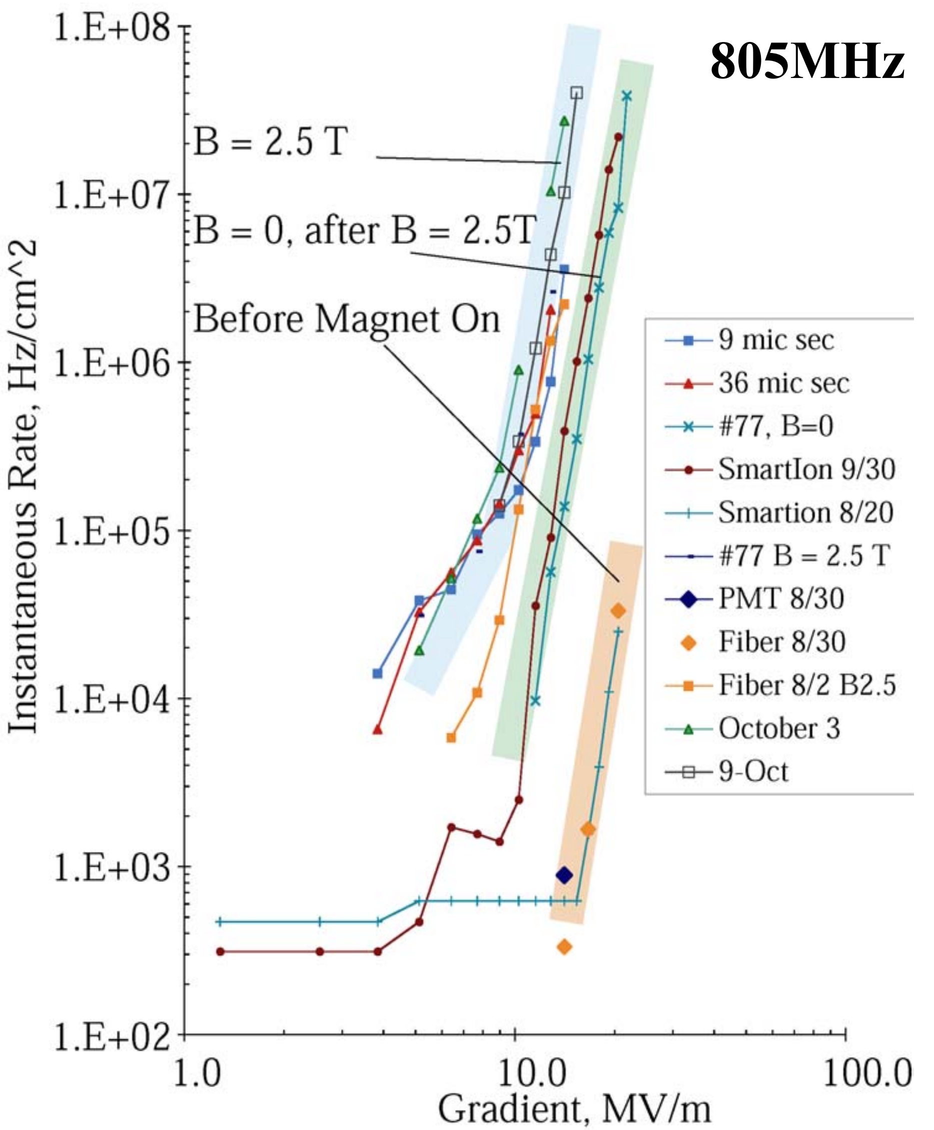


Resolution better than 10% of widths at eq^m emittance

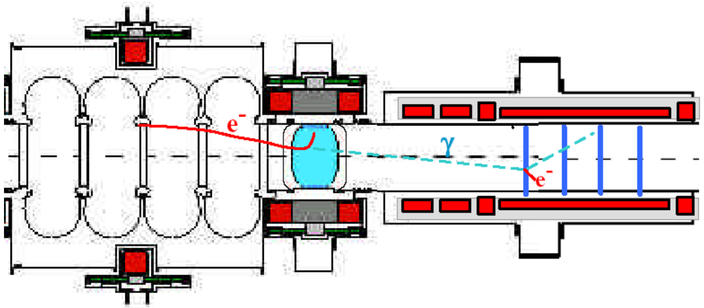
Background: electrons, X-rays



- Instantaneous rate at 8 MV/m (201 MHz): 4×10^{4} Hz/cm^2
- Gives rate/plane = 0.5 MHz (rate/fiber = 116 Hz)
- To reduce noise-hit rate:
  Trigger gate: 15 ns
  On-board TDC resolution 2 ns
  (proposed u/g to board for D0)

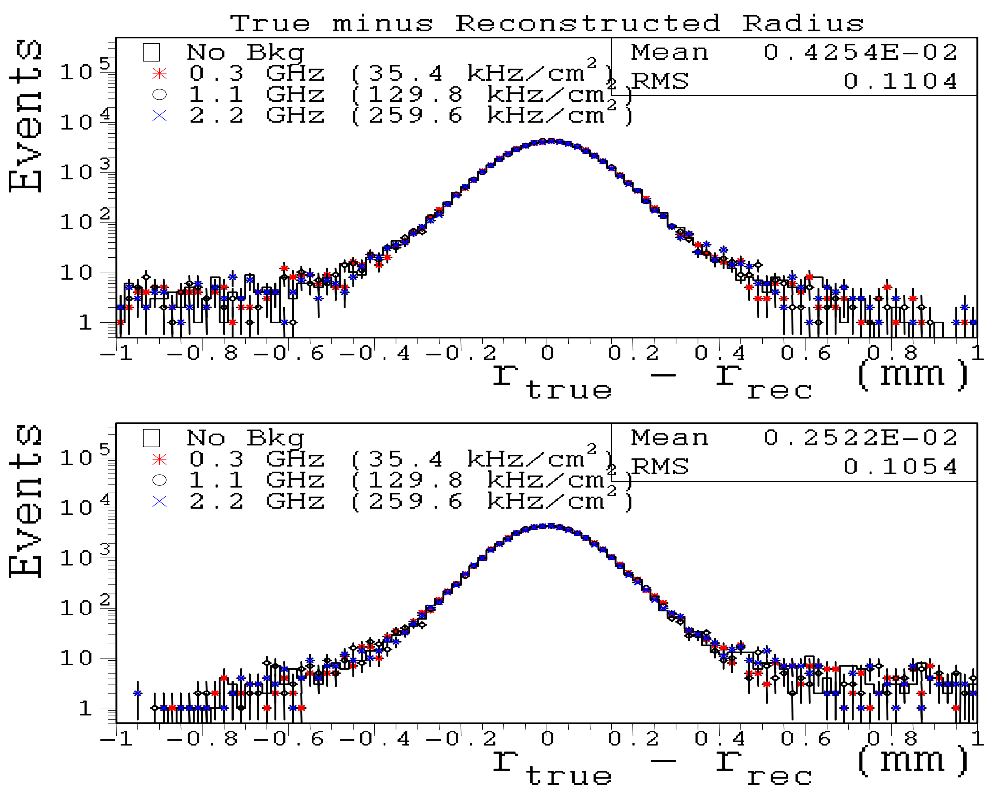


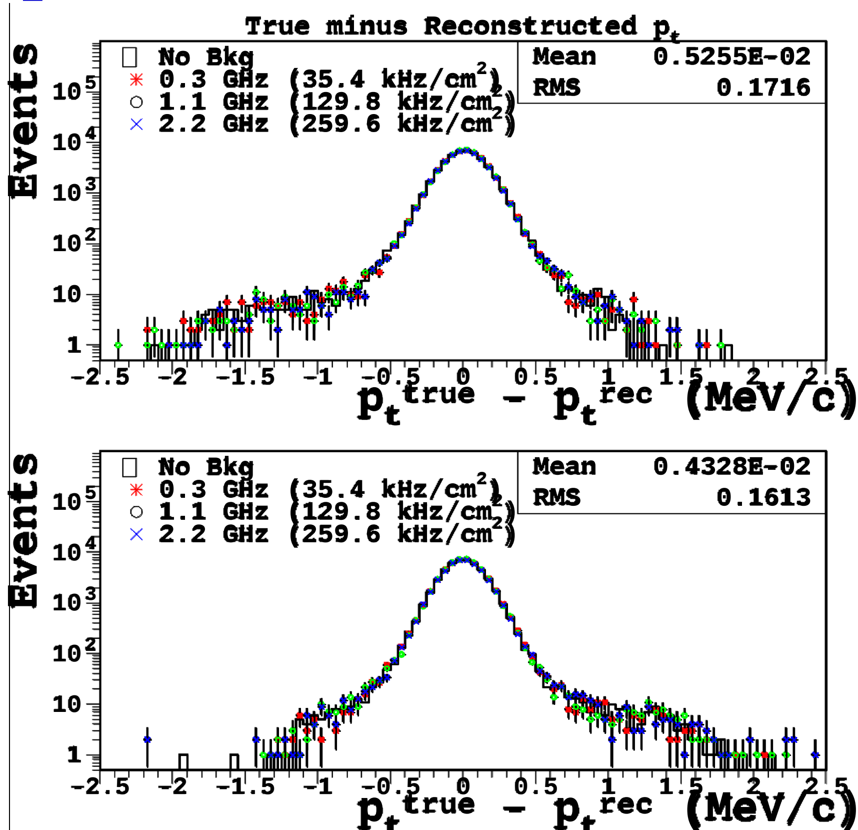
Background tolerance of SciFi tracker



Performance OK

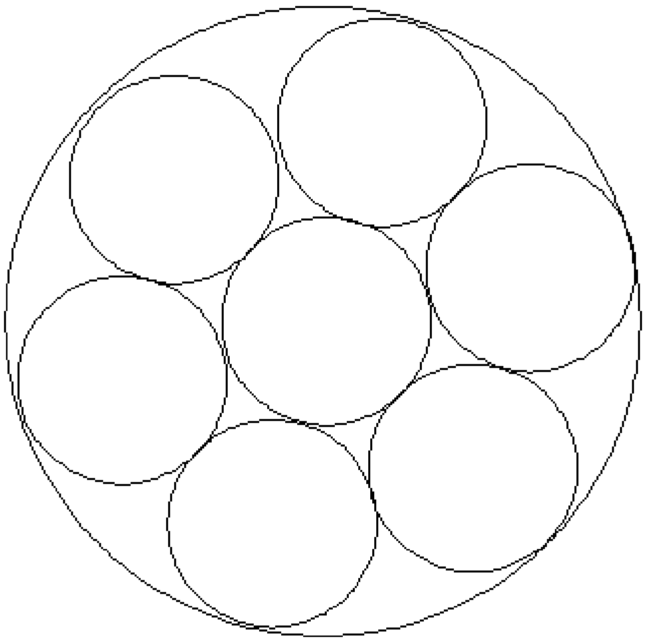
550 MHz/plane

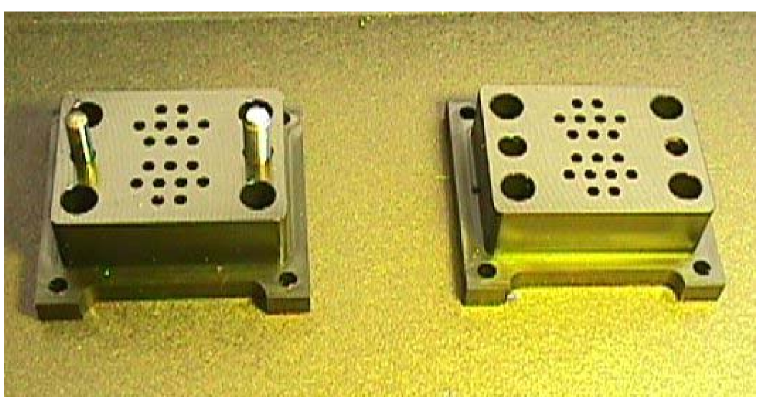




Muon Collaboration

Combining neighboring channels



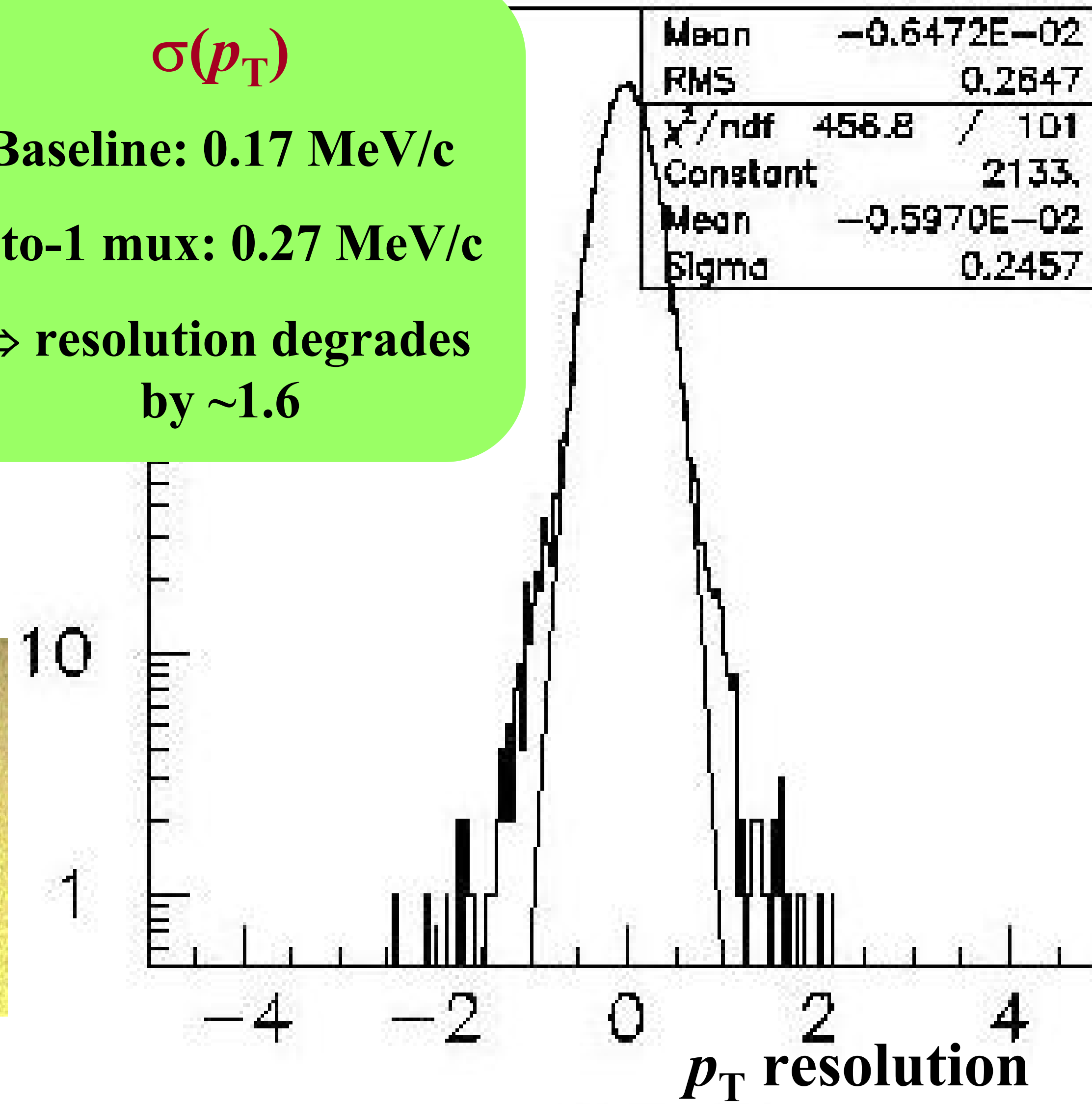


$\sigma(p_T)$

Baseline: 0.17 MeV/c

7-to-1 mux: 0.27 MeV/c

⇒ resolution degrades by ~1.6



MICE Fiber Tracker

- MICE has requested time on DAB VLPC test stand to test prototype in late September/early October
  - Single station, u-v-t
    - Maybe additional partial planes
      - If things go well
    - 7:1 Mux gives 7000 channels/cassette
      - 1 full plane is approximately 4500 ch
  - Cosmic ray trigger
  - Measure light yield primarily
  - Measure sensitivity to RF noise (airborne)
    - To be negotiated with D0
  - Postdoc(s) + students will be here in July to help with D0 tests and thus learn DAQ system
- All are welcome to
  - Observe, comment, criticize, giggle, roll their eyes, etc.